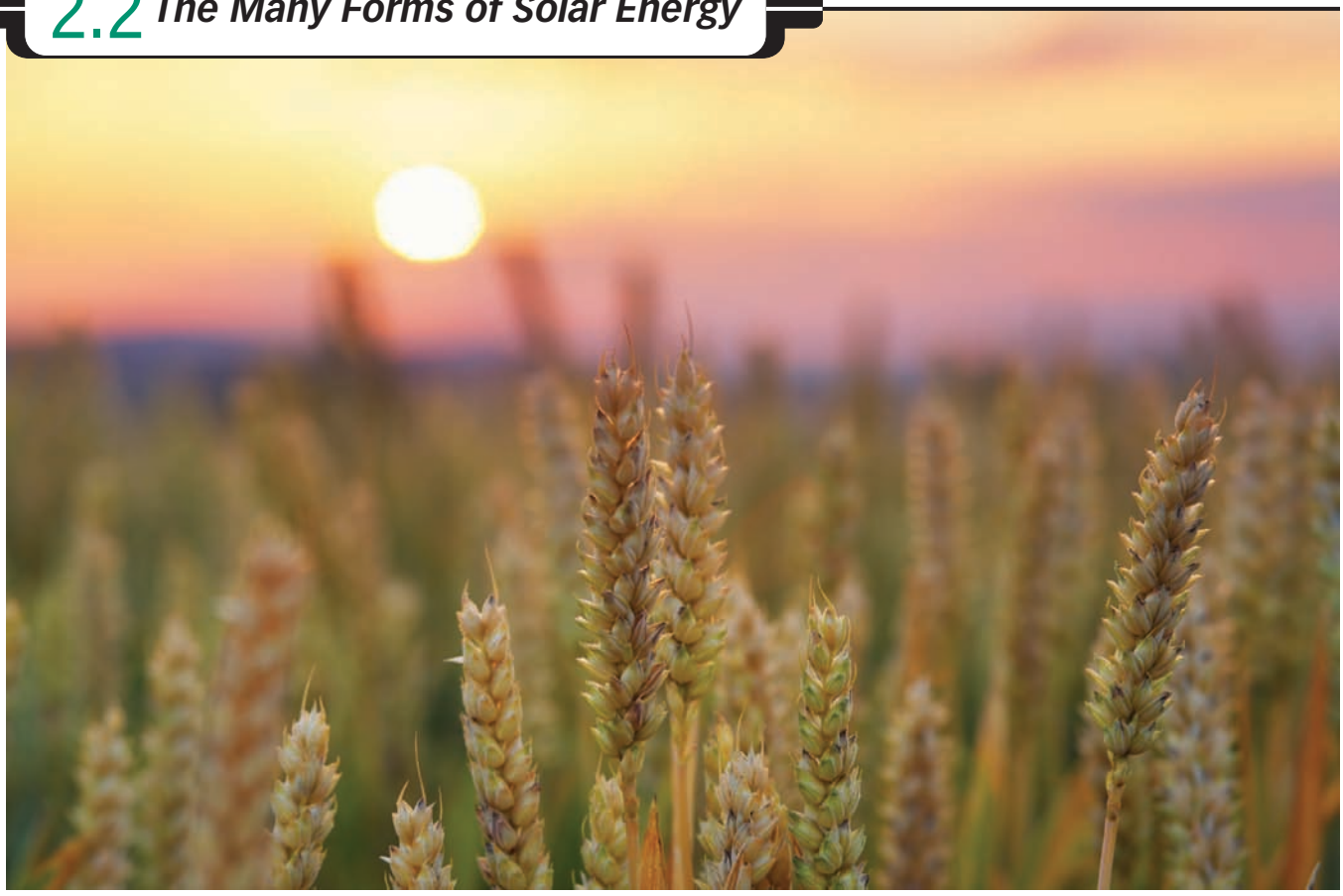
2.2 The Many Forms of Solar Energy



Every second, nuclear fusion reactions in the Sun convert about 4 billion kilograms of mass into energy. Only a tiny fraction of that energy from the Sun strikes Earth (about 1 billionth of the energy produced per year). Some of this energy reaching Earth is trapped by photosynthesis. As you have learned in previous science courses, solar energy is required either directly or indirectly by nearly all the organisms on Earth, including humans. Although only a small fraction of solar energy is captured as chemical potential energy, society's current outlook on energy involves a reliance on the combustion of fossil fuels.

Larger percentages of incoming solar energy are absorbed by land, water, and the atmosphere. Might it be possible to utilize solar energy converted into other energy forms? Could sources of solar energy eliminate the use of non-renewable energy sources (e.g., fossil fuels)? Can solar energy help make sustainable development a reality? In this lesson you will have an opportunity to survey some of the technologies that harness energy from the Sun.

passive solar energy: thermal energy derived from the Sun's radiant energy, absorbed by massive materials, and then transferred naturally to other areas by conduction, convection, and radiation

Passive Solar Energy

Have you ever noticed how a family pet seems to know where the warmest location is in its home? Often, it is near a window, where the pet can nap in the warmth provided by a sunbeam. A home's windows, walls, and floors can be designed to capture and store solar energy in the form of heat. The heat that is transferred to other areas of the building can be referred to as **passive solar energy**, since it is distributed without the need of a mechanical device. This captured energy is distributed by conduction, convection, and radiation.

During winter, the position of the Sun allows electromagnetic radiation to enter a passive solar home through the south-facing window and be absorbed by the concrete floor, as shown in Figure D2.8. When the radiation strikes the floor, the energy of the incoming photons is absorbed by the floor's molecules and transformed into thermal energy. Thermal energy within the floor is then transferred by conduction to regions of the interior space that are at a lower temperature. Thermal energy from the floor can also be transferred to the overlying air. The warmer air over the floor rises and is replaced by denser, cooler air. This creates convection currents in the room. To increase the efficiency of passive solar energy, materials used in a home's construction are designed to enhance the ability to absorb solar radiation. To prevent overheating in the summer, certain home designs (e.g., roof overhangs) help reduce the quantity of solar radiation directly entering the house.

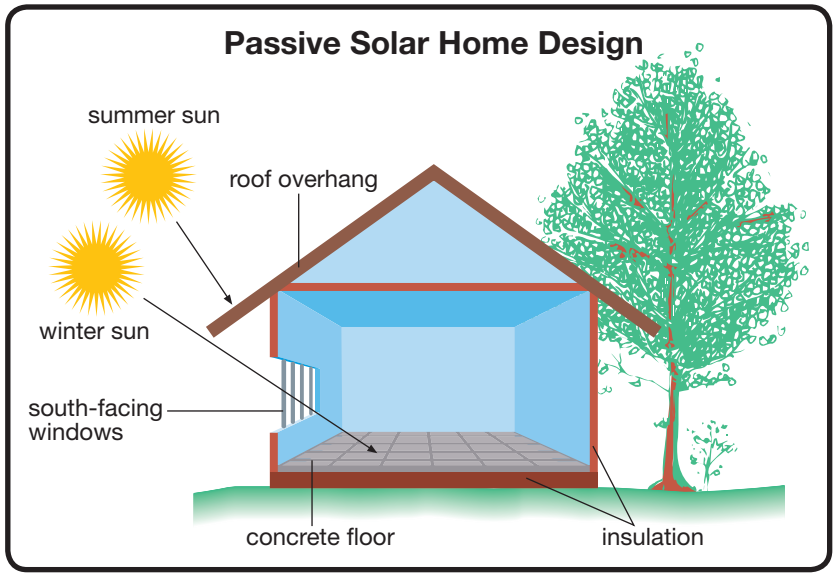
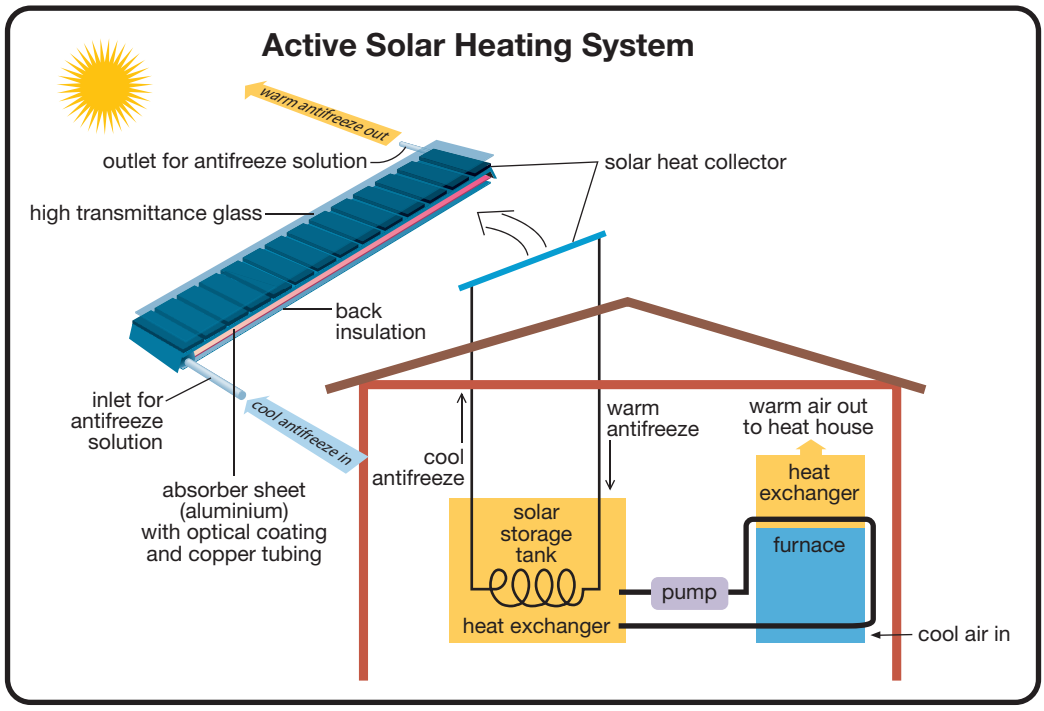


Figure D2.8

Active Solar Energy Technologies

Have you ever boarded a bus on a sunny day and found the seats to be hot to the touch? When solar radiation is absorbed (especially by a black surface), the result is heat. You may have noticed one popular solar technology—a **solar heat collector**—on some buildings. How does this device work to heat buildings? Earlier in this chapter, you saw how solar collectors are used on the roofs of garages in the Drake Landing Solar Community. In fact, over two million homes in North America are equipped with this technology.

solar heat collector: a device that absorbs radiant solar energy and converts it into thermal energy that is carried by a fluid pumped through the collector



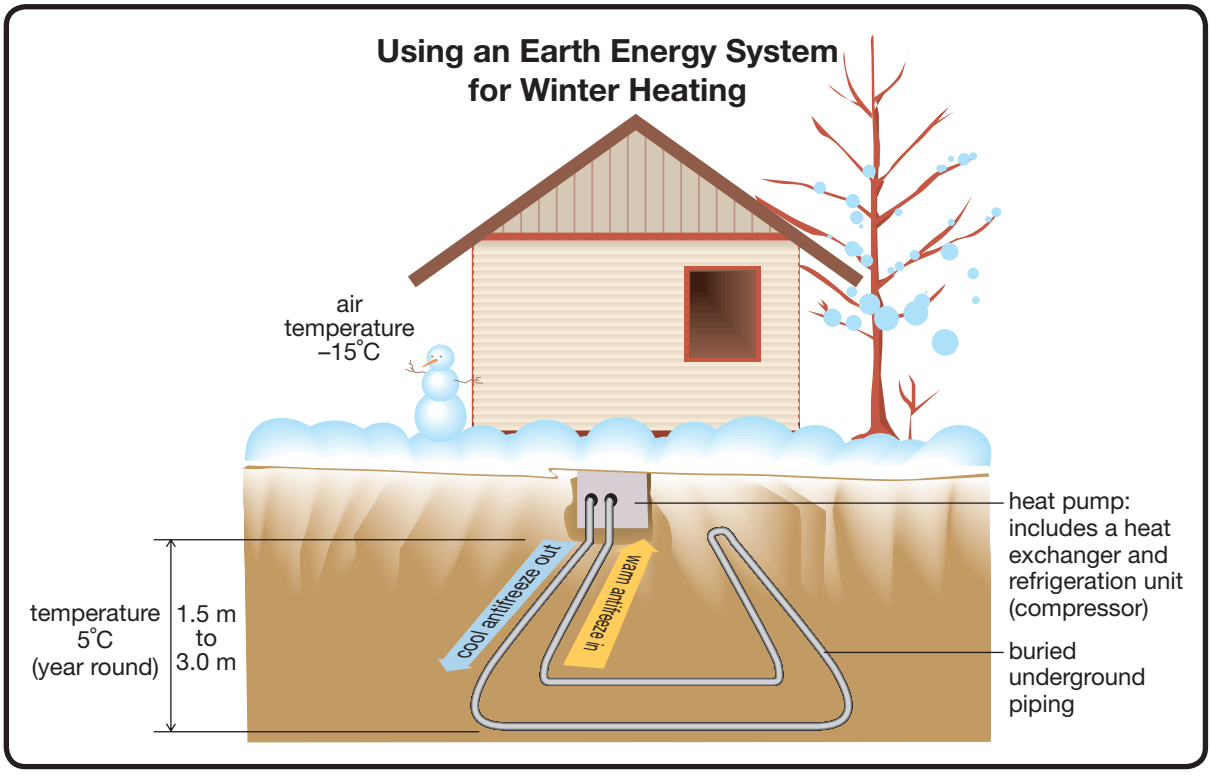
Solar heat collectors typically consist of a flat, black box. Inside the box is a series of pipes that contains an antifreeze solution. As in Drake Landing, rooftop solar heat collectors absorb solar radiation striking the box, allowing a transfer of energy to the fluid inside the pipes. The transfer of energy heats the fluid. The fluid in the system is pumped through the collector and to a heat exchanger, where it releases thermal energy to water in a short-term storage tank. This tank could be located below the collector in the building.

In Drake Landing Solar Community, the short-term storage tank is located in the neighbourhood's energy centre. Recall that for long-term energy storage, the community has a borehole thermal-energy storage system. Warm fluid is pumped into the deep boreholes to make an underground storage system for thermal energy. Since Drake Landing is a new community, it is expected to take years for the ground surrounding the boreholes to become fully charged with thermal energy. Once operational, the thermal energy stored from the summer months should enable the long-term storage system to meet most of the community's heating needs during the winter season.

Earth Energy Systems

Earth's surface absorbs over half of the incoming solar energy it receives. This is a huge amount of energy that, until recently, remained largely untapped. **Earth energy systems** work much like rooftop solar collectors except they use the ground like a single giant solar heat collector. Incoming solar radiation and heat radiated from inside Earth absorbed by the ground is converted into thermal energy. As you saw in your investigation of the Drake Landing renewable energy systems, warmed earth can act as an energy-storage reservoir. Weather changes that cause the atmosphere's temperature to fluctuate do not affect the temperature below ground, which remains much more constant year-round.

earth energy system: a heating system that uses a loop of piping through the ground to absorb thermal energy



The design of an earth energy system consists of a network of pipes installed underground to collect heat. These pipes can be arranged vertically in deep holes or horizontally in shallow trenches. The pipes are filled with a circulating antifreeze solution. During winter, thermal energy from the ground is transferred to the antifreeze where it can be extracted and used to heat the building. Although the temperature of the earth on the prairies is around 5°C, a heat-pump system similar to that used in a refrigerator, except run in reverse, concentrates the heat from the earth, allowing it to be delivered throughout the house. Earth energy systems are a proven technology, with some systems having been in operation since the 1940s. According to Natural Resources Canada, over 30 000 Canadian buildings are now heated and/or cooled using earth energy systems. Earth energy systems are expensive to install, but they require very little additional energy to operate, eventually providing a cost savings and reduced reliance on fossil fuels.

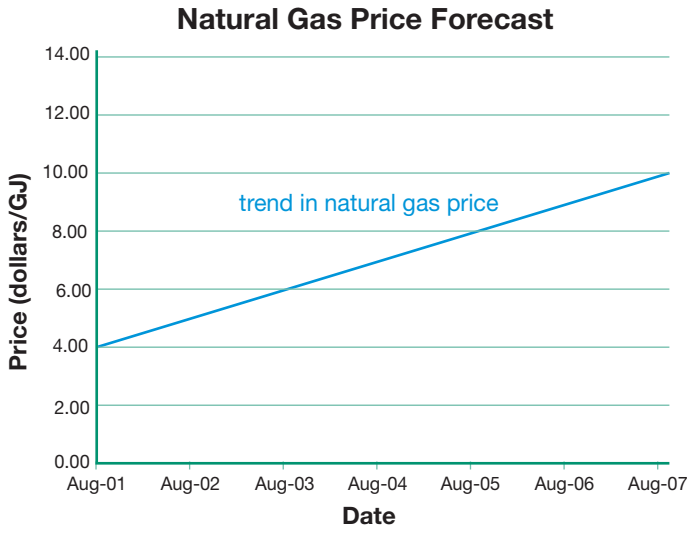
Practice

11. Explain how passive solar heating and other solar-energy systems involve the use of a renewable energy source.

12. Explain how earth energy systems are technology based on a renewable source of energy.

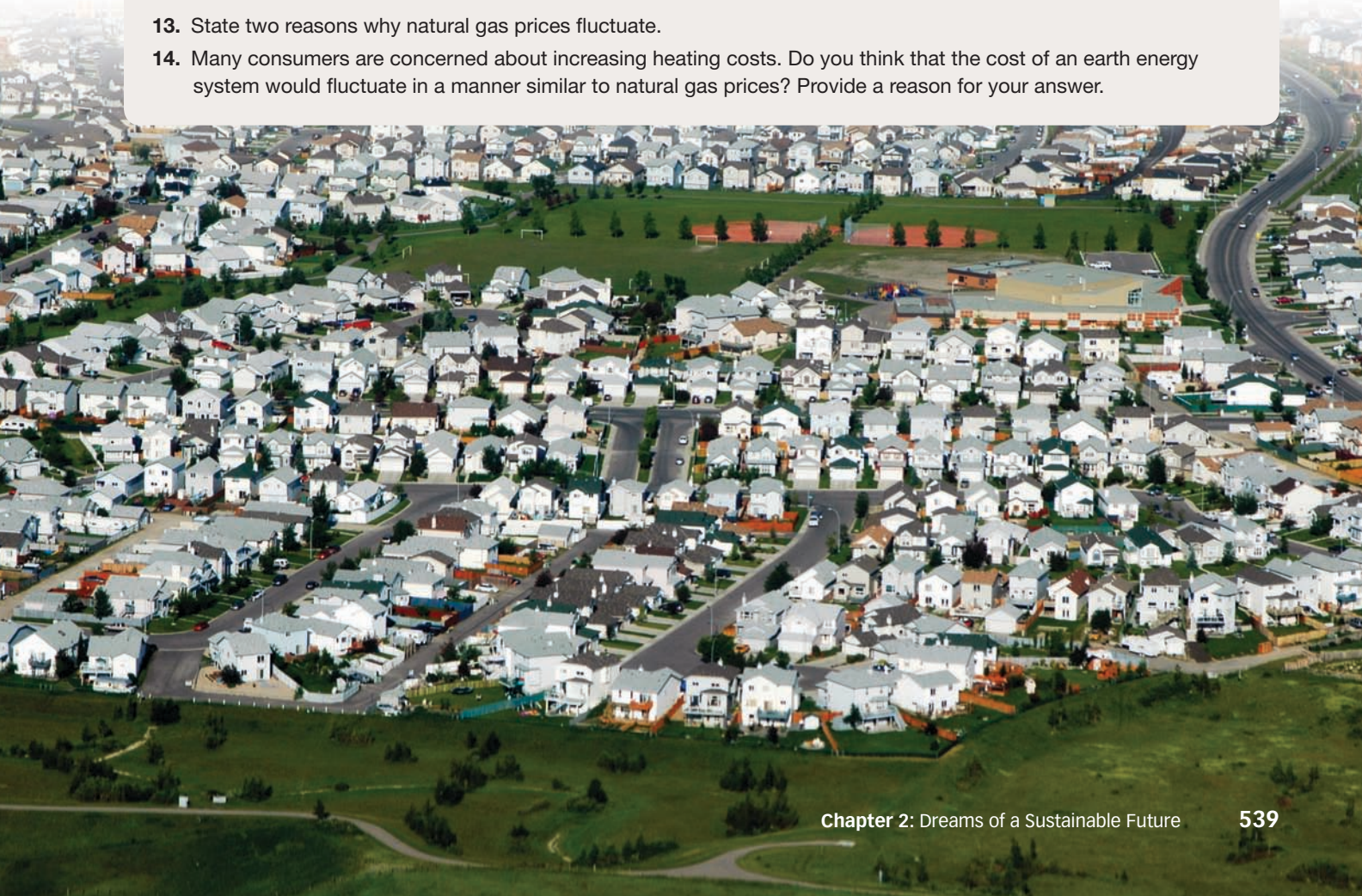
Use the following information to answer questions 13 and 14.

Users of natural gas in Canada often encounter price fluctuations from month to month. Due to its finite supply, the price of natural gas is undergoing an upward trend.



13. State two reasons why natural gas prices fluctuate.

14. Many consumers are concerned about increasing heating costs. Do you think that the cost of an earth energy system would fluctuate in a manner similar to natural gas prices? Provide a reason for your answer.



Photovoltaic Cells—Electricity Directly from EMR

In Unit C, a **photovoltaic cell** was used in many of the investigations that explored the properties of electromagnetic radiation (EMR). Photovoltaic cells convert radiant energy in a manner quite similar to what occurs in photosynthesis. When a photon of electromagnetic radiation is absorbed by a photovoltaic cell, atoms of the light-sensitive material within the cell eject electrons. Brighter light sources provide the cell with a larger population of photons, resulting in a larger number of electrons that are ejected. Recall that moving electrons form an electric current (Unit C). Since the energy given to each of the electrons is relatively small, the current is weak (as shown in Figure D2.9, where the cell tested has a voltage output of less than half a volt). The low energy efficiency of photovoltaic cells can restrict their use to low-power devices, such as calculators. Connecting many photovoltaic cells together, forming an array, produces more energetic electric currents; but this requires a large area.

photovoltaic cell: a device that converts electromagnetic radiation into electrical energy

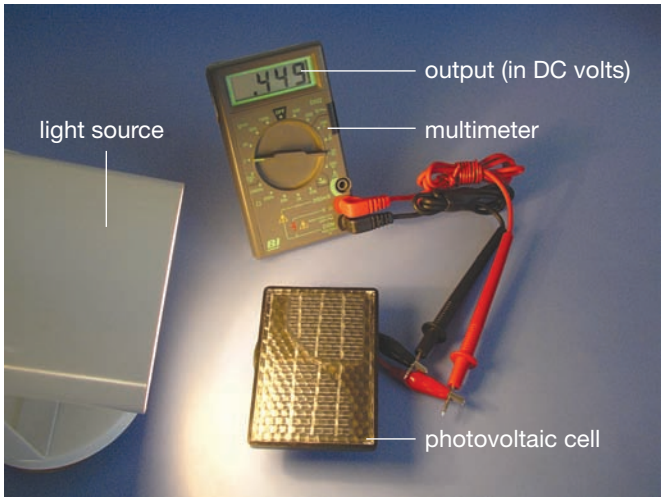


Figure D2.9

Figure D2.10: An array of photovoltaic cells can provide sufficient electrical energy for electrical devices.

Photovoltaic Cells for Home and Business

Given that photovoltaic cells are renewable sources of energy that produces no emissions during their operation, it is natural to wonder why photovoltaic cells have yet to be used on a large scale for homes and businesses.

One reason photovoltaic cells aren't used on a large scale is that they don't work in the dark. That means batteries are needed for use at night or on overcast days. Second, photovoltaic cells produce direct current (DC) electricity. Most appliances used in homes and businesses use alternating current (AC) electricity, meaning that an inverter is needed to convert the DC current into an AC current. Third, photovoltaic cells are not very efficient. Heavy-duty applications, like operating large appliances, require huge arrays of cells that cover an enormous area. This is not practical. Finally, photovoltaic cells are expensive to produce and require toxic heavy metals, like arsenic and cadmium. Strict adherence to safety guidelines is necessary to produce photovoltaic cells without harming humans or the environment.

Despite these challenges, photovoltaic cells are being used in an increasing number of applications: as energy sources for small devices and as supplemental or back-up power to primary power systems. As further improvements are made to the manufacturing process, the cost of photovoltaic cells, batteries, and inverters may decrease. This low cost will most likey make photovoltaic cells a more attractive alternative.

Figure D2.11: This garden lantern uses a photovoltaic cell to charge a small battery pack during the day so it is able to light a walkway at night.

DID YOU KNOW?

The area of photovoltaic arrays used to provide electrical energy to the International Space Station (ISS) is slightly larger than the end zone of a Canadian football field. The reflection of unabsorbed sunlight from the surface of the arrays on the ISS makes it the brightest object in the night sky when viewed from Earth. You can use the Internet to find the time and position from which the ISS can be seen in the night sky.

Practice

15. When white light lands on the surface of a photovoltaic cell, photons from all regions of the visible spectrum deliver energy to the light-sensitive materials.

a. Sketch a diagram to show red, green, and violet photons landing on the surface of a photovoltaic cell.

b. Which type of photon—a photon of red light or a photon of violet light—delivers the most energy to the photovoltaic cell.

16. Obtain the document "Determining Sustainability of Technologies" from the Science 30 Textbook CD. Follow the instructions in the document to determine the overall sustainability of photovoltaic cells as an energy source. **Note:** Keep your completed checklist for photovoltaic cells because you will be asked to refer to it throughout this chapter.

Hydroelectric Power

Moving water possesses kinetic energy. One of the oldest technologies to utilize water's energy is the water wheel. Earliest records of water wheels date back to 400 BC, when they were used by Greeks to grind grain. Later, in Europe, water wheels powered the saws, pumps, and machinery in a variety of mills.

Kinetic energy of flowing water is an important energy source that is often used to generate electricity. Hydroelectric power supplies about 19% of the world's electricity. Over 95% of Quebec's electrical energy production comes from the energy of flowing water—the largest percentage of any province. The ability to produce excess electricity beyond provincial demand enables Quebec to sell much of the electricity it generates to cities in the United States.

Figure D2.12: Water wheels have been used throughout history to power a variety of machines. As water falls from a higher elevation to a lower elevation, the wheel converts the water's gravitational potential energy into kinetic energy.

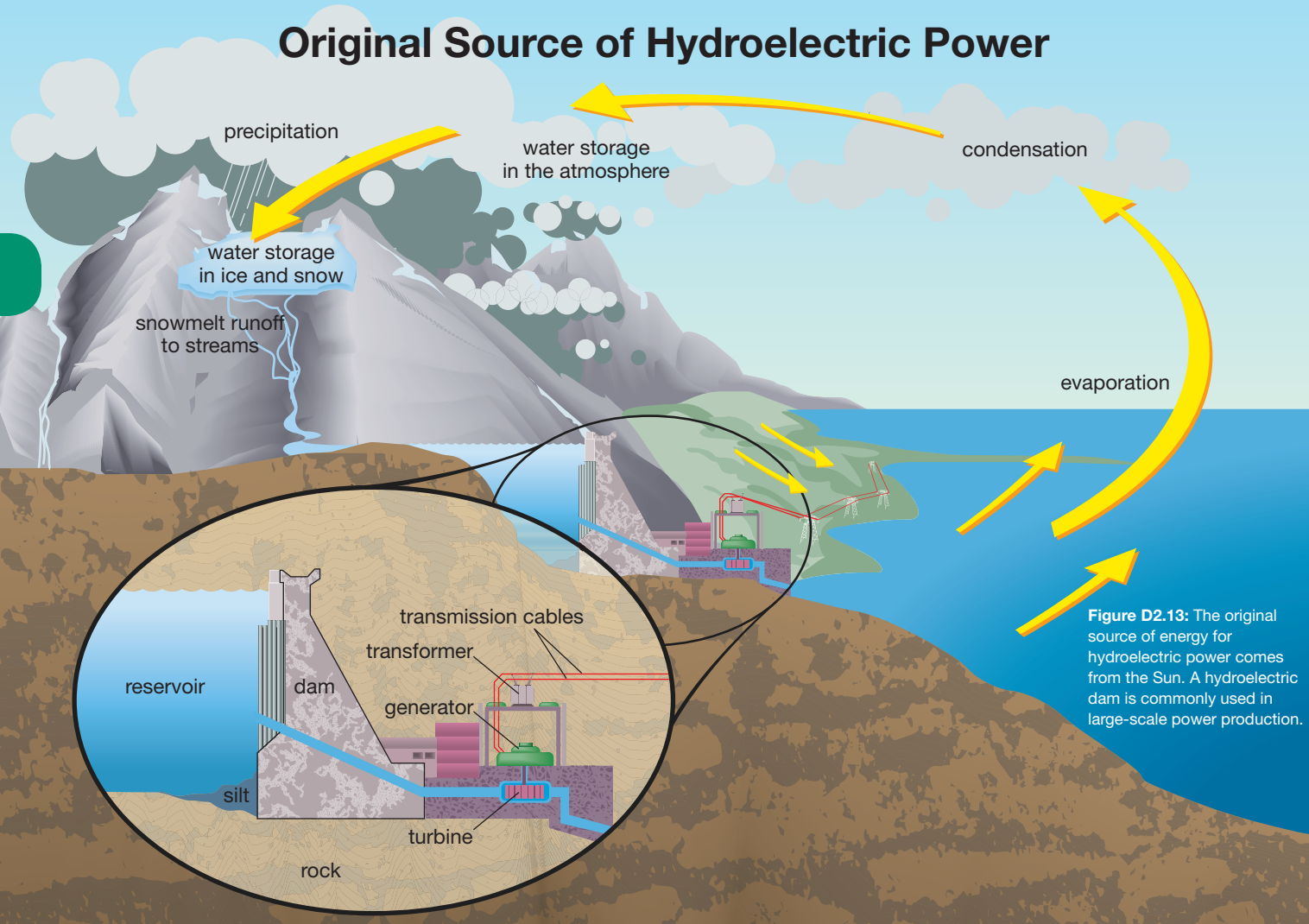


Figure D2.13: The original source of energy for hydroelectric power comes from the Sun. A hydroelectric dam is commonly used in large-scale power production.

In Lesson 2.1 you prepared process maps for some technologies that convert energy. What would a process map for hydroelectric energy look like? Is hydroelectric power a renewable energy? It may surprise you to know that the original energy source for hydroelectric power is the Sun. Water heated by solar radiation at lower elevations evaporates, allowing it to rise and be carried by air currents in the atmosphere, often over great distances. Eventually, water vapour condenses, forming clouds and precipitation. Precipitation that falls at higher elevations has gained gravitational potential energy, which can be converted into kinetic energy once it begins to run downhill. Since the energy from the Sun is inexhaustible, hydroelectric power, like other solar-based technologies, are processes providing renewable energy.

Dams are commonly used to convert gravitational potential energy of water into electricity. Dams can concentrate and control the energy in moving water by storing it in a large reservoir. In some dams, the difference in height between the reservoir and the turbines is over 200 m. The higher the water level, the faster the water flows through the turbine (increasing the kinetic energy). The force of the flowing water pushes against turbine blades, causing them to turn. As with other technologies you have evaluated, the turbines are attached to generators that convert the kinetic energy into electrical energy. The electrical energy from the generators is transferred to transformers that increase the voltage so that energy loss due to resistance in the transmission lines is minimized.

Hydroelectricity in Alberta

Hydroelectric dams in Alberta currently supply about 5% of the province's electricity. This low value, which is less than many other provinces, may be the result of the plentiful supply of coal in Alberta, which is used to generate over 75% of Alberta's electrical energy. Although some people suggest that Alberta should be utilizing more hydroelectric power, as you'll see in the next activity, the development of large-scale hydroelectric projects requires careful consideration of ecological, societal, and economic risks and benefits.

Assessing Hydroelectric Power

As an energy source, hydroelectric power has many strengths:

- The underlying energy source is the Sun, making it a renewable source of energy.
- Power production does not release any harmful emissions into the environment.
- The water used is not polluted or consumed as it passes through the turbines and is able to re-enter the water cycle.
- Very little waste heat is generated, meaning that this is a very efficient process. (Over 80% of the gravitational potential energy of the water is transformed into electrical energy.)
- The high energy efficiency enables the cost per kilowatt-hour of energy produced to be relatively low.

Major criticisms of hydroelectric power focus on the environmental impact resulting from the reservoir of water held behind the dam. As the reservoir fills, large areas of land are covered with water. This may include usable farmland, forests, and even cities. The action of flooding such areas may have an impact on the natural aquatic ecosystem. Dams impede the movement of nutrient-rich silt carried by the flow of the river that is important to the fertility of land downstream. In some situations, leaching of metal ions occurs from soils in the flooded area, affecting the quality of water in the river. These factors can put enormous stresses on species living upstream and downstream of the reservoir. Societal concerns include the potential for the forced relocation of entire communities that may have inhabited the area for long periods of time, resulting in the loss of archaeological sites and cultural artifacts.

Any area to be developed for the collection of hydroelectricity must demonstrate suitable geography and rainfall patterns. In addition, the location should be geologically stable to reduce possible damage to the structure from the effects of earthquakes.

Figure D2.14: The Oldman Dam near Pincher Creek, Alberta, provides 25 MW of electrical energy as well as water for irrigating crops in southern Alberta.

Try This Activity

Making a Decision About Hydroelectric Dam Construction

Purpose

In this activity you will review a document summarizing a decision made in response to a proposal to build a hydroelectric dam on a river in northern Alberta. Many impacts of hydroelectric dams are identified within the decision.

Problem

What are the risks and benefits of hydroelectric dams? What perspectives are considered when making decisions regarding the development of hydroelectric projects?

Procedure

Read the "Hydroelectric Dam Construction" handout from the Science 30 Textbook CD.

Analysis

1. Prepare a risk-benefit analysis of hydroelectric dams.
2. Prepare a list of perspectives considered in the decision.
3. Evaluate the decision made regarding the proposed hydroelectric project. In your evaluation, comment on whether relevant risks and benefits was accurately assessed and whether a suitable range of perspectives was considered in making this decision.

Practice

17. In Figure D2.13 showing the original source of hydroelectric power, a large transformer is shown above the generator.

a. Explain why a transformer is vital to the transmission of electricity from the hydroelectric plant to distant consumers.

b. Determine whether a step-up transformer or a step-down transformer is required.

18. Obtain the document "Determining Sustainability of Technologies" from the Science 30 Textbook CD. Follow the instructions in the document to determine the overall sustainability of hydroelectric dams as an energy technology. **Note:** Keep your completed checklist for hydroelectric power because you will be asked to refer to it throughout this chapter.

Use the following information to answer questions 19 to 21.

The Three Gorges Dam spans the world's third-largest river, the Yangtze River in China. This project began in 1997 and, when completed, will be the largest dam in the world. The Three Gorges Dam will span 2 km, and the power plant will be capable of generating 18 000 MW of electrical energy.

ENERGY DATA FOR CHINA

Electricity Production (2006)	
2.83×10^5 MW	
Energy Source for Electricity Production	**Percentage of Energy Produced**
coal	83%
hydro	14%
nuclear	2%
other	1%

Four Criticisms of the Three Gorges Dam

I. 1.3 million people have been displaced by the construction of the dam and flooding of the reservoir.
II. The flooded reservoir area contains former factories, industrial centres, and garbage dumps, resulting in pollution to the Yangtze River.
III. The construction of the dam could result in the extinction of some rare species of fish.
IV. The location of the Three Gorges Dam is near six seismic faults that have demonstrated activity.

19. Calculate the percentage of China's electricity production that could be met once the Three Gorges Dam is operating at full capacity.

20. Identify the impact that power production from the Three Gorges Dam could have on China in terms of societal and ecological impact.

21. Respond to one of the criticisms of the Three Gorges Dam project listed, by defending the project.

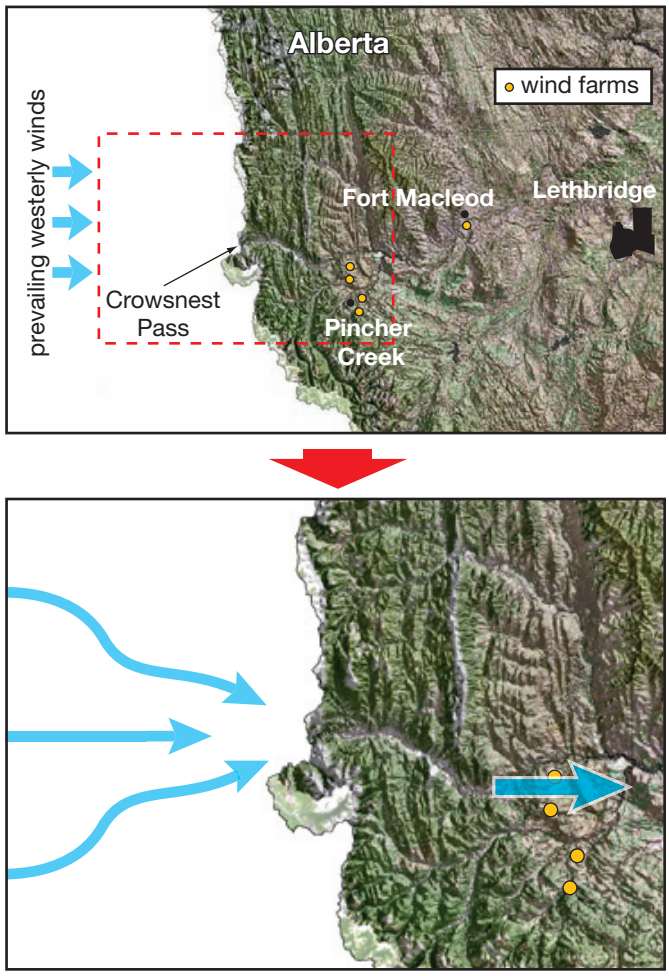
Wind Energy

Have you ever been on the streets of a large city on a windy day? Tall buildings can dramatically intensify the speed of the wind, turning some streets into virtual wind tunnels. The effect that buildings have on wind is similar to the change to water flowing down a stream that suddenly narrows. Since the same volume of water is rushing through a narrower opening, its speed must pick up. You might be surprised to know that this same effect makes the southwestern corner of Alberta one of the best places on Earth to harness wind energy.

Figure D2.15: These wind turbines, along with hundreds of others, generate electricity by converting the energy from the steady, high winds in certain regions of Alberta.

Earlier you reviewed the effect that thermal energy has in creating air currents. Solar energy can be converted into thermal energy, which affects the kinetic energy and density of molecules in the air. As air molecules absorb thermal energy, they move faster and take up more space, thus decreasing in density. In Unit B you learned that the predominant direction of winds across the prairies is from the west, and that these winds are created by the combination of global convection currents and Earth's rotation. In some parts of Alberta, the westerly winds are especially strong and have become a source of energy.

Locations of Larger Wind Farms in Southern Alberta



In western Canada, numerous ranges of mountains form natural barriers to these westerly winds. However, when the prevailing winds encounter a gap between mountains, like at Crowsnest Pass, the energy of the wind becomes concentrated as it is funnelled through the narrow opening between mountains. The wind follows the valleys and travels east into southern Alberta. Elevation drops as the mountains give way to the foothills and then to the prairies. Other atmospheric effects further intensify the kinetic energy of the wind. The end result is that places like Pincher Creek, Fort Macleod, and Lethbridge have wind conditions ideally suited to run wind turbines. The kinetic energy of the moving air pushes against the blades of a wind turbine and causes the blades to spin. As is the case with all electric generating apparatus, a spinning turbine connected to a generator converts the kinetic energy of the spinning blades into electrical energy.

Figure D2.16: Two technicians inspect the enormous blade of a wind turbine.

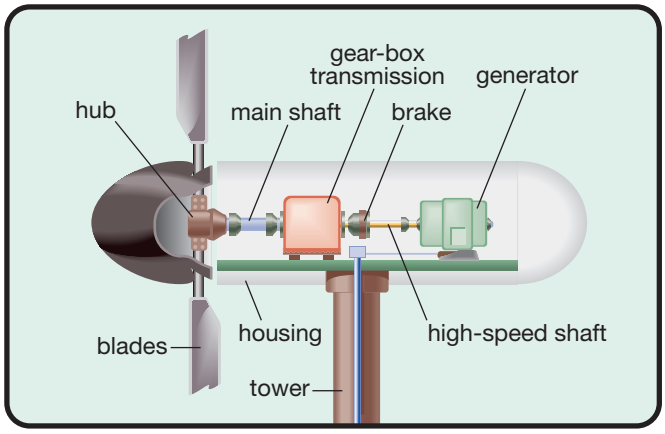


Figure D2.17: The kinetic energy of the spinning blades is transferred to the generator, which transforms it into electrical energy.

There is a great deal of interest in wind energy. Currently, wind energy is the fastest growing form of electricity generation in Canada. However, it provides only a small portion of Canada's electricity. As you learned earlier, the ultimate source of energy for wind power is the Sun, making wind energy a renewable resource. It is impossible for air to be "used up" during the process and there are no harmful emissions. Wind energy is also very versatile. Large wind farms—made up of hundreds of turbines—have the ability to supply electricity to communities; and single, smaller turbines can be used to meet the electricity demands for a single isolated home.

The limitations of wind energy are similar to those of other renewable sources. As you have learned, only certain locations have the proper conditions to allow for suitable, nearly constant winds. Wind energy also shares two drawbacks associated with photovoltaic cells: the energy source can be quite variable from day to day and the conversion into electrical energy is not very efficient. In the case of wind energy, only about 30% of the energy in the wind is transformed into electrical energy. This means that generating a significant amount of electrical energy requires many wind turbines that occupy a large area. Although the land used for a wind farm can also be used for grazing livestock or for other agricultural activities, it still must be set aside.

Other effects of wind energy have emerged since the technology has been used. In Alberta, scientists at the University of Calgary have been investigating the effect that the moving blades of the turbines have on bat populations. Similar concerns exist over the number of birds killed by the blades of wind turbines. Some landowners report that the noise produced by the rotating blades can be annoying and that the site of the giant turbines is a form of visual pollution—as it ruins the view of the landscape.

Practice

22. Describe the factors that make the area around Pincher Creek well-suited for harvesting wind energy.

23. Obtain the document "Determining Sustainability of Technologies" from the Science 30 Textbook CD. Follow the instructions in the document to determine the overall sustainability of wind energy as an energy source. **Note:** Keep your completed checklist for wind energy because you will be asked to refer to it throughout this chapter.

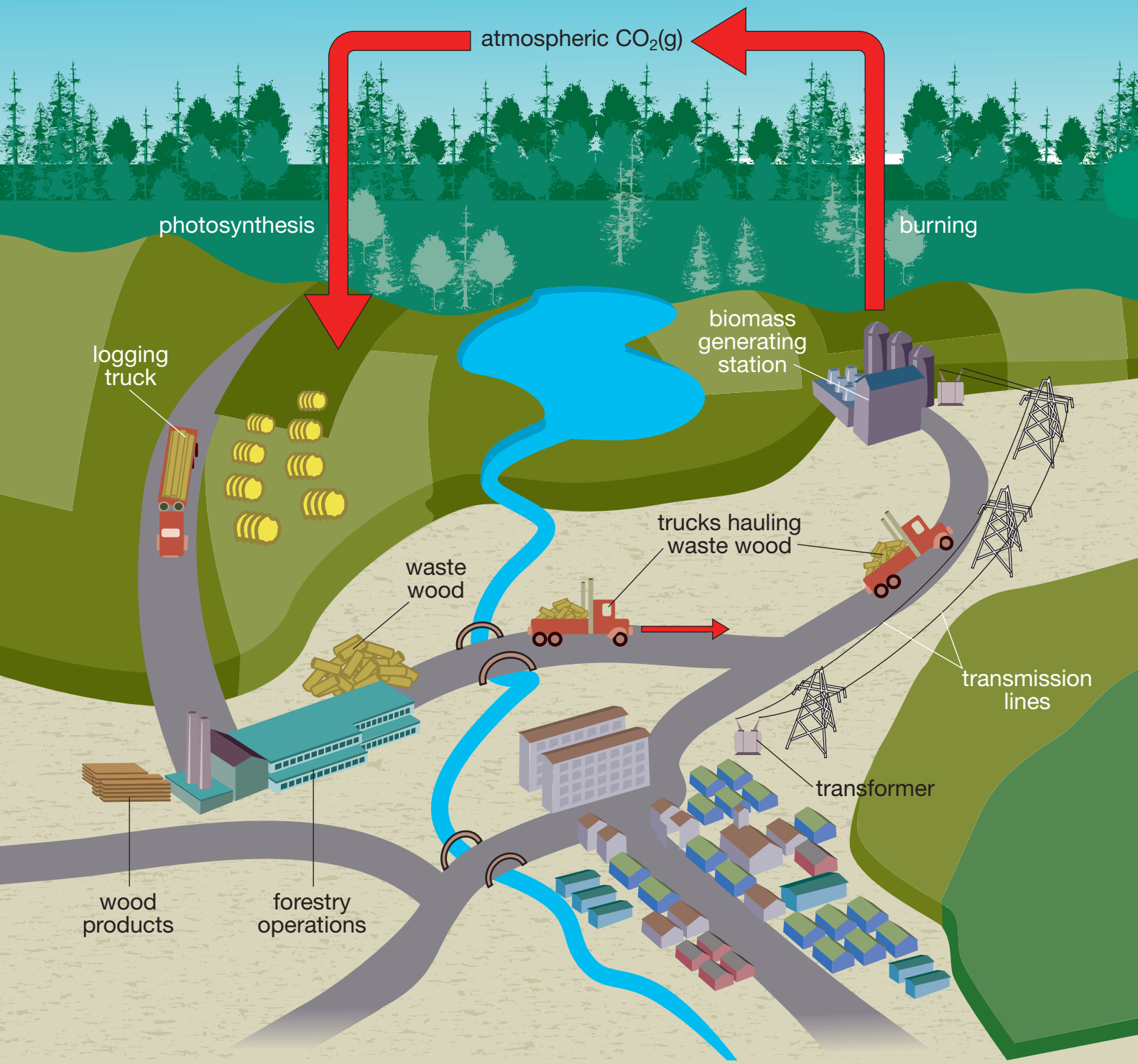
Biomass

You have learned that many energy sources used by society can be traced back to solar energy. Photosynthesis—the chemical reaction that converts the Sun's radiant energy into chemical potential energy—allows plant material to be used as an energy source either as food or as **biomass**. The chemical potential energy within recently living organic material such as wood, corn, or organic waste can be used as a source of renewable and potentially sustainable energy.

biomass: plant matter or agricultural waste from recently living sources used as a fuel or as an energy source

Figure D2.18: Wood, an example of biomass, was likely the first fuel used by humans for heating and cooking.

Biomass Energy—Emission and Absorption of CO_2



DID YOU KNOW?

Biomass refers to organic matter from living or recently living sources. Fossil fuels are not considered biomass because they were derived from plants and animals that died millions of years ago.

Direct Combustion—Generating Electricity Using Biomass

Modern forestry operations produce waste wood products, such as timber debris, sawdust, and wood chips. Waste wood can be sent to a landfill or be combusted on site, but neither of these processes provides an opportunity to reduce emissions or use the energy remaining in this biomass.

The generating station (shown in Figure D2.19) in Whitecourt uses waste wood from nearby forestry operations to produce electricity. The combustion of the waste wood within a furnace is used to heat boilers that produce the steam needed to drive turbines connected to generators. The Whitecourt Generating Station utilizes modern emissions-control technology to reduce the release of particulate matter and oxides of nitrogen.

Although the plant material is combusted, resulting in carbon dioxide emissions, biomass can be produced in a sustainable manner. Sustainability involves the absorption of carbon dioxide by the next generation of plant material. Earlier in this lesson you prepared a process map demonstrating the interrelationship between combustion and photosynthesis. The combination of combustion and crop planting to absorb carbon dioxide make biomass energy use a "carbon-neutral" process. When biomass fuels are used in place of fossil fuels, the carbon in the non-renewable fossil fuels stays in the ground. Estimates indicate that biomass power production is not exactly carbon-neutral, releasing just under 40 g of carbon dioxide per kilowatt-hour of electrical energy produced. As you discovered in Unit C, this value compares favourably to conventional coal-fired plants, which emit about 1000 g of carbon dioxide for every kilowatt-hour of electrical energy produced.

Figure D2.19: The Whitecourt Generating Station uses waste wood products as a fuel to produce steam for electricity production.

Figure D2.20: Waste wood piled outside a mill

Practice

24. Refer to the illustration "Biomass Energy—Emission and Absorption of CO_2" on page 547.

- **a.** Identify any activity depicted in the illustration that increases CO_2 emissions, affecting the ability of the process depicted to be carbon-neutral.
- **b.** The illustration focuses on the energy derived from waste wood products. Identify other sources of biomass that could also be used to generate electricity.

25. Obtain the document "Determining Sustainability of Technologies" from the Science 30 Textbook CD. Follow the instructions given in the document to determine the overall sustainability of generating electricity from biomass. **Note:** Keep your completed checklist for biomass because you will be asked to refer to it throughout this chapter.

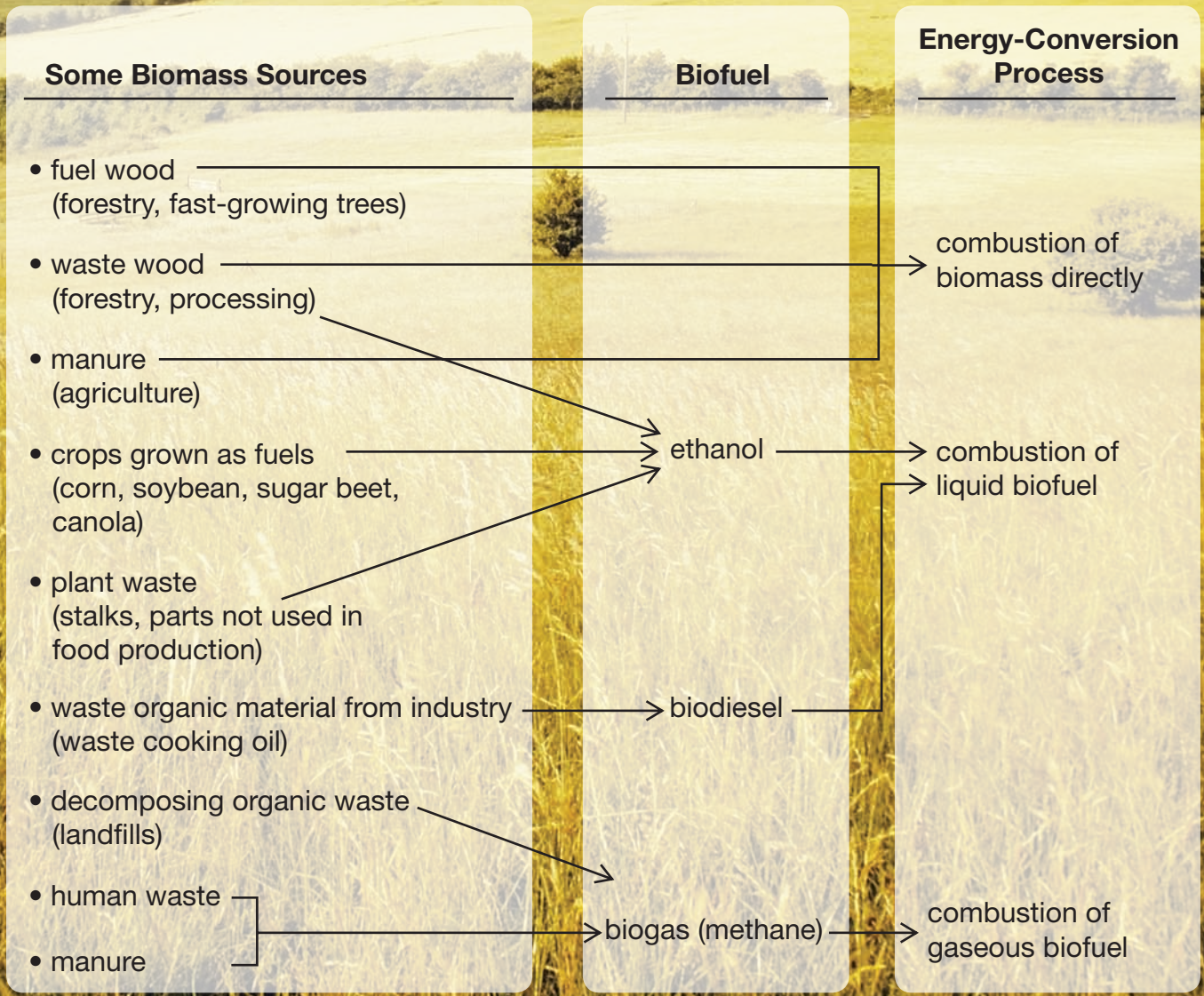
Biofuels

Biomass as an energy source has many advantages. Usable sources of biomass tend to be readily available; and since most forms are combustible, complex technology is not required to use them. If society is to consider using biomass fuels to develop improved energy sustainability, the largest advantage of biomass is the ability to convert it into a **biofuel**. Methane, ethanol, and the mixtures in biodiesel are composed of high-energy molecules. This means that the biomass energy they produce can be applied to a great number of technologies including automobiles.

biofuel: a fuel produced from renewable biological resources, including biomass

DID YOU KNOW?

The quantity of solar energy absorbed by photosynthesis is almost ten times greater than the current world energy demand. Using biomass makes some of this energy available for use.



Ethanol in Gasoline

In Unit B you studied alcohols. Ethanol, an alcohol, is a highly usable biofuel that can be produced using yeast to ferment the sugars within organic matter like crop plants and even waste wood. Humans have used yeast to produce ethanol to make alcoholic beverages for thousands of years. As you learned, alcohols like ethanol are combustible, making them an excellent fuel.

Ethanol produced from biomass is currently blended with gasoline. New automobiles can operate with gasoline containing up to 10% ethanol, with some special models being able to use gasoline containing up to 85% ethanol. Small amounts of ethanol can also be added to diesel; but at high percentages, modifications to the engine are necessary.

Figure D2.21: Ethanol, $C_2H_5OH(l)$, can be produced by fermenting grain, corn, wood, or other plant products. Ethanol can be combusted directly or blended with gasoline as a way to reduce the content of nonrenewable substances in gasoline.

Ethanol from biomass is considered to be a renewable energy source because it is derived from crops that can be continually grown. In Brazil, ethanol for gasoline is produced using sugar cane. The growth of new crops absorb carbon dioxide from the atmosphere, enabling the production of new biomass and making the process sustainable. Brazil's use of biomass has significantly reduced the country's reliance on oil imports and has reduced its contribution to global climate change.

A major criticism of biomass energy focuses on the large amount of land needed for the growth of the crops and on the decision to use a potential food source as a fuel for transportation. Throughout your studies in Unit B, you discovered that current agricultural practices include the use of fertilizers, herbicides, and pesticides. These practices can have adverse effects on the environment. It is hoped that any increase in crop production for use in making biofuels will be accompanied by sustainable agricultural practices.

An additional concern involve the loss of efficiency in the making of a biofuel. You have learned in this unit that whenever energy is converted, there is a loss of some of the input. Critics of biofuel production cite two sources of inefficiency. First, biofuels produce methane and ethanol, which contain few carbons, making them low-energy molecules compared to the complex organic molecules from which they were derived. Second, high concentrations of ethanol are toxic to many organisms, including the yeast involved in the fermentation process. This toxicity means that it is difficult to produce sufficient ethanol to meet projected demands. Currently, scientists are working on developing strains of micro-organisms that will continue to ferment biomass at higher ethanol concentrations. It is hoped that efforts to develop these micro-organisms will improve the efficiency of biofuel production and increase the potential for biomass use.

Landfill Gas

Garbage in a landfill is sealed off from oxygen by the layers of garbage and dirt above it. Under these oxygen-free conditions, bacteria digest organic waste and release methane—the main component of natural gas. This biogas can be collected using a network of pipes and then used as a fuel for the production of electricity. Many major cities, like Calgary, Edmonton, and Grande Prairie, have constructed landfills to allow for the collection of biogas. At the Clover Bar Landfill in Edmonton, a 4.8-MW biogas facility produces enough electricity for 4600 Edmonton homes.

Biogas can also be collected from feedlots or other intensive agriculture operations where manure is allowed to decompose in the absence of oxygen.

Biodiesel

The chemical potential energy within waste oils can be a source of energy. In the "Determining Heat of Combustion" investigation on page 494, you learned that organic molecules containing many carbon atoms can store a large quantity of chemical potential energy. You also learned from your study in Unit B that fats and oils are esters of large organic acid molecules joined to a glycerol molecule. In some automobile engines, waste cooking oil can be used directly as a fuel. Biodiesel is a mixture of organic acids obtained from the conversion of waste cooking oil and diesel fuel. The reaction to produce biodiesel from waste cooking oil involves breaking the bonds within the molecules of the ester functional groups within the chemical structure of the waste cooking oil. Breaking the ester bonds helps maintain the proper viscosity of the resulting biodiesel. The blending of biodiesel with conventional diesel fuel is designed to maintain the energy content of the product and decrease the amount of fossil fuels consumed.

Practice

26. Burning ethanol releases carbon dioxide. Identify aspects of ecological sustainability associated with the production and combustion of the biofuels ethanol and biodiesel (formed from canola or other vegetable oils).

27. Biogas often contains impurities like hydrogen sulfide, $H_2S(g)$. Identify possible problems associated with the combustion of biogas containing hydrogen sulfide.

Hydrogen—Fuel of the Future?

Research into the use of biodiesel is one attempt to reduce the use of fossil fuels as the main energy source for transportation. Another approach is the development of the hydrogen fuel cell.

In many ways, a fuel cell is similar to an electrochemical cell. It consists of two electrodes separated by a membrane that allows ions to pass. Electrons extracted by the reaction of the fuel in the cell flow through an external circuit to any electrical device, like a car's electric motor. Without a constant supply of reactants, power production from a fuel cell immediately stops.

A variety of fuel cells exist, but one of the most tested types is the hydrogen fuel cell. Hydrogen enters the fuel cell at one electrode while its reactant—oxygen—enters the fuel cell at the other electrode. Within the fuel cell, the two reactants never come into direct contact; but each reactant is absorbed by opposite sides of a material containing a catalyst. The catalyst allows hydrogen to react in such a way that it provides electrons for the external circuit as well as positively charged ions that migrate through the membrane to complete the flow of charge. The changes during the operation of the fuel cell (as shown in Figure D2.22) result in a flameless combustion reaction between hydrogen and oxygen that produces an electric current rather than a flame.

In 2006, the use of hydrogen fuel cells in Canada was uncommon. Five buses equipped with hydrogen fuel cells in Victoria and Vancouver were some of very few examples where this technology was used. But with more research and development, fuel-cell automobiles may become an increasingly common sight. Currently, the application of the technology is limited by the high cost for the catalysts used in fuel cells and the size of the cells required limit application of the technology. Researchers are optimistic because the hydrogen fuel cell is a very energy-efficient device that has only one emission—water vapour.

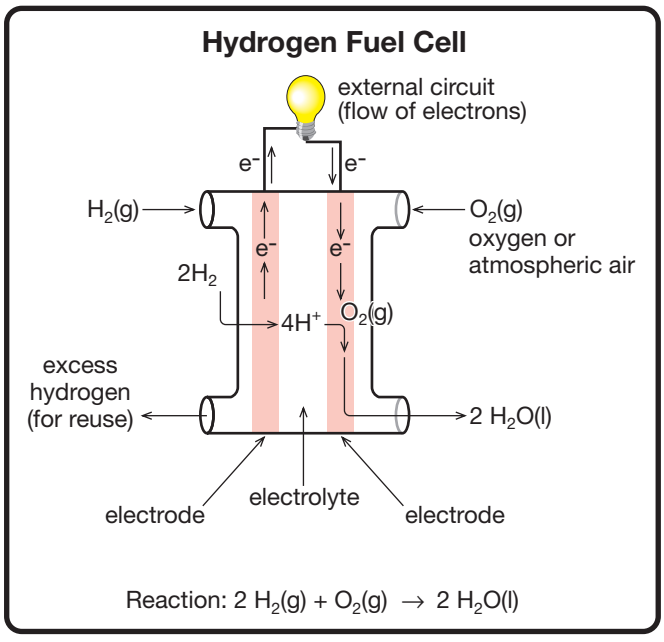


Figure D2.22

A major drawback to the wide-scale use of hydrogen fuels is the limited supply of hydrogen. Elemental hydrogen, $H_2(g)$, is not readily available; but it can be extracted from hydrocarbons or water, both energy-rich molecules. Hydrocarbons, for example CH_4, and water, H_2O, are possible hydrogen sources. The process of removing hydrogen from these two possible sources is not without controversy. Removing hydrogen from hydrocarbons can involve a process called steam reformation. Industrially, the reformation and additional reactions to produce hydrogen result in the formation of carbon monoxide, carbon dioxide, and coke (C(s)).

Decomposition of Water

$$2\,H_2O(l) \xrightarrow{\text{electrical energy}} 2\,H_2(g) + O_2(g)$$

In previous science courses, you may have observed the electrolysis of water, where an electric current is applied to water, resulting in the decomposition of water. In order for fuel cells to be a sustainable technology, the electricity used for electrolysis must come from a renewable source (e.g., wind, nuclear, solar, or hydro). In addition, the source of the water that is electrolyzed must also come from a renewable source. Concerns over drought and a decrease in drinkable water may cause seawater to become a likely source for hydrogen to power cars in the future.

Try This Activity

Producing Hydrogen Fuel

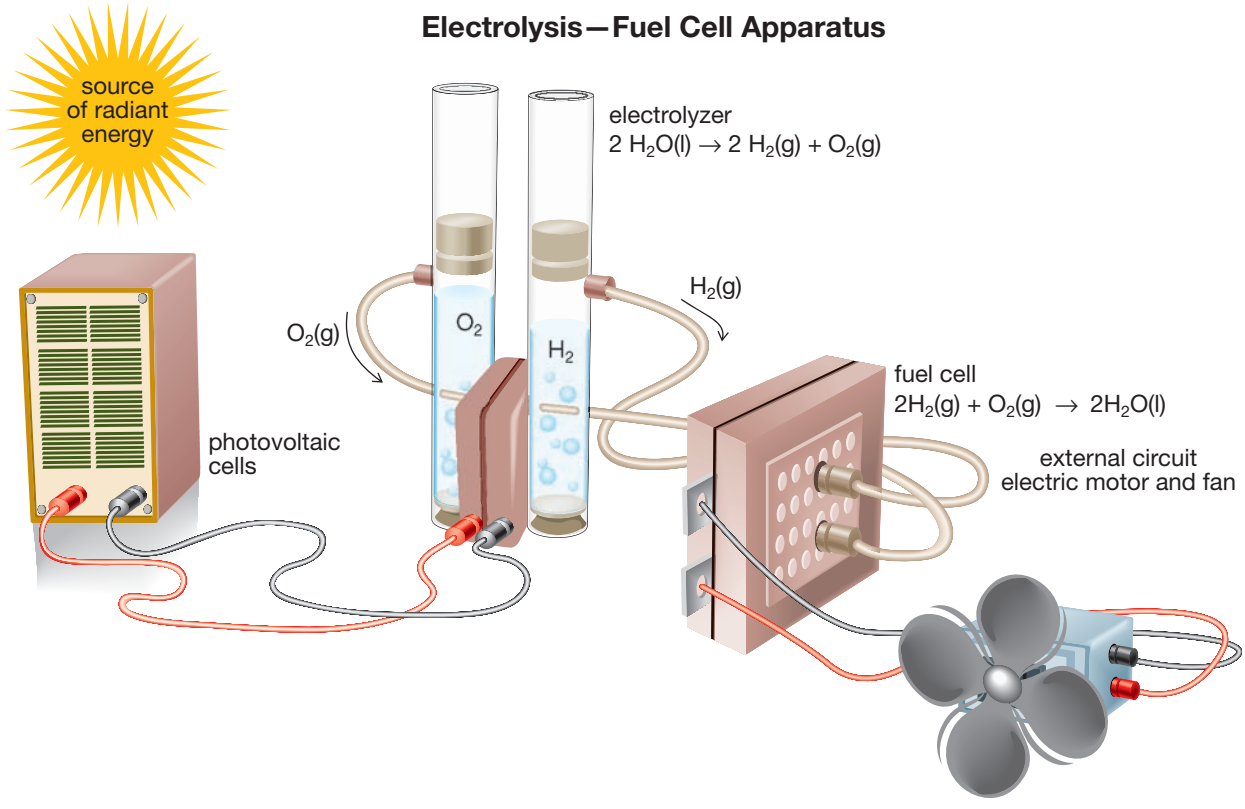
Purpose

You will examine an illustration depicting the transformation of water to produce the hydrogen needed to operate a hydrogen fuel cell, and you will identify the energy forms and transformations involved.

Science Skills

✓ Analyzing and Interpreting

Electrolysis—Fuel Cell Apparatus



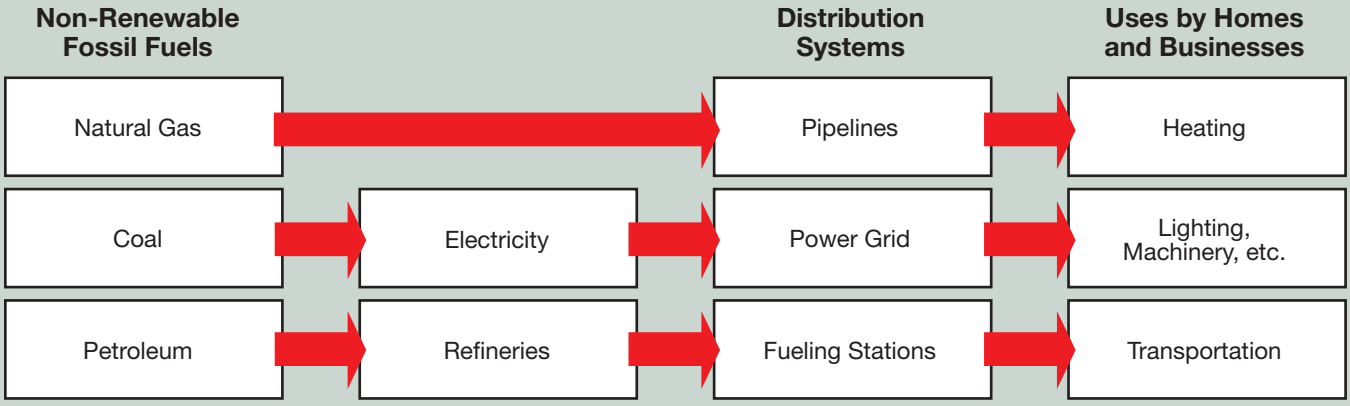
Analysis

Use an energy-flow diagram to describe the energy forms and transformations that occur during the operation of the apparatus shown in the illustration.

From the Carbon Economy to the Hydrogen Economy

Which energy sources do societies depend upon the most? Presently, particularly in Alberta, there is a heavy dependence on coal for electricity, natural gas for heating, and petroleum for transportation. All of these forms of energy are non-renewable and increase the levels of atmospheric carbon dioxide. A phrase used to describe this dependence on fossil fuels is the **carbon economy**. Due to the non-renewable nature of fossil fuels, the carbon economy is simply not sustainable.

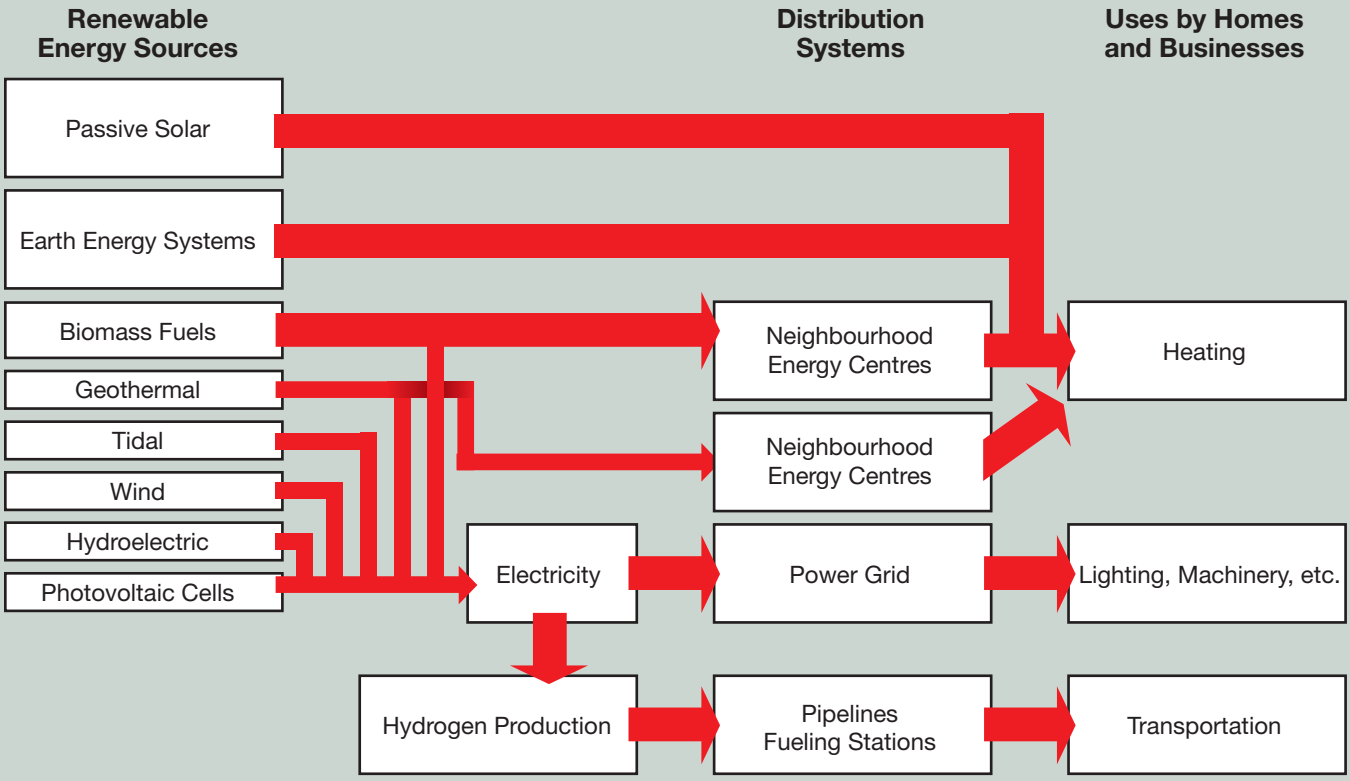
The Carbon Economy



Many people think that within the next twenty years, hydrocarbons will no longer be primary sources of energy and that renewable energy sources will have increasing importance. One proposal calls for the use of renewable energy sources to generate electricity and for the use of hydrogen fuel cells in vehicles. Such a proposal would make hydrogen a primary fuel and result in the development of a **hydrogen economy**.

- **carbon economy:** an economy that depends on fossil fuels as the primary source of energy, resulting in excessive emissions of carbon dioxide
- **hydrogen economy:** an economy that depends on renewable sources of energy to generate electricity and depends upon hydrogen as the fuel for transportation

The Hydrogen Economy



When comparing the diagrams of the carbon economy and the hydrogen economy, you can see that a greater variety of energy sources are required to support the increased use of hydrogen. To make the proposed hydrogen economy a success, creative combinations of many energy sources must be used, along with different distribution systems. In the Drake Landing Solar Community, the energy centre provides heat to the homes in the neighbourhood. For more remote dwellings, heating needs might be met by earth energy systems located in the homeowner's backyard.

Try This Activity

Converting to the Hydrogen Economy

Purpose

You will work with other students to identify changes to your home or community if it were to convert to the hydrogen economy.

Science Skills

- ✓ Analyzing and Interpreting
- ✓ Communication and Teamwork

Procedure and Analysis

1. Identify non-sustainable energy technologies used in your home or community.
2. Identify sustainable technologies and strategies that could be used to replace the non-sustainable technologies identified in question 1.
3. Indicate major differences between the current carbon economy and the hydrogen economy.
4. Predict problems and solutions that might occur within your home or community during the conversion to the hydrogen economy.
5. Some countries in Europe have adopted twenty- and thirty-year plans that will move them toward a hydrogen economy. To fund the conversion, tax rebates are given to people who make the necessary changes to their buildings, means of transportation, and energy infrastructure. These rebates are partially funded by "carbon taxes" on technologies that are based on the old carbon economy. For example, the use of large, inefficient vehicles (like SUVs) is discouraged by high gasoline taxes. Public transportation is heavily subsidized and rebates are offered to people who purchase more-efficient, smaller vehicles with new technology. Do you think these strategies would work in Alberta?

One Future, Many Paths

What do you think your community will be like in twenty years? Will you see photovoltaic cells on nearly every rooftop? Will you see neighbourhood energy centres providing homeowners with energy from renewable sources? As you have seen, choosing which technology to use to produce energy involves many perspectives and should address aspects of ecological, societal, and economic sustainability. Finding workable solutions to energy issues may not only involve overcoming technological challenges, it may also involve changing attitudes and behaviours. Behaviours and attitudes stem from culture: the beliefs, values, and symbols passed down from one generation to the next and shared by a community. This line of thought suggests that the greatest challenges ahead relate to the cultural dimension of sustainable development. Does this sound familiar?

Earlier in this course you were introduced to traditional ecological knowledge, which involves developing an understanding of human interactions with the environment and focusing on the inseparable relationship between land, resources, and culture. It could be that a holistic approach—which brings the human aspects of knowledge, spirit, and emotion into decision making—may prove to be very helpful in making sustainable development a reality.

DID YOU KNOW?

Hydrogen fuel cells have been around since the 1960s to provide electricity for spacecraft. The *Apollo 13* crisis was a result of an explosion that reduced the supply of oxygen to the fuel cells, reducing the electricity available to maintain the spacecraft.

2.2 Summary

The quantity of solar energy reaching Earth each day exceeds the world's energy demand. The main problem is finding a way to harness solar energy that is cost-competitive with fossil fuels. Unlike fossil fuels, solar technologies are renewable and avoid many of the negative effects to human health and the environment. Solar technologies can be high tech or low tech and large scale or small scale. They also can generate heat or electricity. Solar technologies have a wide range of applications and are likely to play an important role in the world's future energy production. As renewable technologies improve and fossil fuels become more expensive because of shrinking supplies, renewable forms of energy will become more commonly used throughout the world.

2.2 Questions

Knowledge

1. Define each of the following terms.
   - **a.** passive solar energy
   - **b.** earth energy system
   - **c.** biomass
   - **d.** hydrogen economy
2. Describe the energy conversions involved during the use of each of the following technologies.
   - **a.** photovoltaic cells
   - **b.** hydroelectric power
3. Describe one way you could use solar energy to reduce your household energy costs without purchasing any new equipment.
4. Identify the main limitations and benefits of solar-energy technologies.

Applying Concepts

5. Explain how the operation of an earth energy system is similar to your body's circulatory system.
6. List actions that you and your family perform that are consistent with sustainable development. In each case, identify whether the action addresses ecological sustainability, environmental sustainability, societal sustainability, or any combination of these.
7. Earlier in this chapter you evaluated six energy sources—coal, nuclear fission, photovoltaic cells, hydroelectric power, wind energy, and biomass—for sustainability as sources of energy. You will need these six completed evaluations to answer questions 7.a. and 7.b.
   - **a.** Summarize your findings by producing a table that compares the weighted scores for each category of sustainability as well as the overall score for each source of energy.
   - **b.** Refer to your table to discuss the overall rankings, from highest to lowest, of the sources of energy. Support your findings by describing the overall reasons for your ranking.

Chapter 2 Summary

Alberta relies heavily on non-renewable energy sources. Hydrocarbons provide the main fuels for transportation, heating, and electricity. Because these sources will eventually run out and because their continued use has associated environmental costs, more sustainable energy sources and technologies are needed. Renewable technologies include hydroelectricity, tidal, wind, solar, biomass fuels, geothermal, and hydrogen fuel cells. Switching to more renewable technologies will be necessary to meet Alberta's future energy needs. Other strategies, such as increasing efficiency and reducing waste, will also be important in reducing Alberta's growing energy demand.

Summarize Your Learning

In this chapter you examined a number of new terms, concepts, and techniques for problem solving. You will have a much easier time recalling and applying the information you learned if you take some time to organize it into some sort of pattern. Now that you have come to the end of the chapter, this is an appropriate time to focus on the patterns within the things that you have learned.

Since the pattern has to be in a form that is meaningful to you, you have some options as to how you can create this summary. Each of the following summary techniques is described in "Summarize Your Learning Activities" in the Reference section.

Option 1: Draw a concept map or a web diagram.	Option 2: Create a point-form summary.	Option 3: Write a story using key terms and concepts.	Option 4: Create a colourful poster.	Option 5: Build a model.	Option 6: Write a script for a skit (a mock news report).

Chapter 2 Review Questions

Knowledge

1. The following table summarizes the important renewable technologies studied in this chapter. Copy and complete the table in your notebook.

Renewable Technology	Original Energy Source	Main Use (e.g., heating, electricity)	Key Advantages	Key Disadvantages
hydroelectric				
tidal				
wind				
solar				
earth energy system				
photovoltaic cell				
geothermal				
biomass				
hydrogen fuel cell				

2. The title of this chapter is "Dreams of a Sustainable Future."
   a. Explain the meaning of the term *sustainable development*.
   b. A sustainable source of energy must satisfy criteria in three broad categories of sustainability. Describe the key characteristics that describe each of these categories.
3. Describe two renewable ways an individual household can generate electricity.
4. Describe the energy transformations that occur when electricity is produced from geothermal energy. Begin with the original source of the energy and finish with electricity.
5. Identify one way geothermal energy is used other than to generate electricity.
6. Identify the range of materials classified as biomass. Explain how each of the materials listed can be used as a source of energy.
7. Describe the energy changes associated with a hydrogen fuel cell. Identify limitations to the use of the fuel cell.
8. The "pop test" is commonly used to identify the presence of hydrogen. In a "pop test" a very small quantity of hydrogen is brought into contact with a burning splint. The combustion of the hydrogen produces a flame and a small explosion, resulting in a popping sound. Compare the reactions for hydrogen in a fuel cell with the combustion of hydrogen in a "pop test." Which process has the greatest energy efficiency? Support your reason.
9. Describe the two main ways hydrogen can be produced for use in hydrogen fuel cells.
10. Describe how a hydrogen economy might work in the future. Identify two challenges and two benefits associated with developing a hydrogen economy.

Applying Concepts

11. Compare hydroelectric energy with tidal energy. List the similarities and differences.
12. Iceland is a country that has officially committed to switching from a carbon economy to a hydrogen economy. Briefly describe how this hydrogen economy could best be supported by sources of renewable energy in Iceland.
13. Note that nuclear fission does not appear as an entry in the hydrogen economy or in the carbon economy. Yet many people think that nuclear power could play a critical role in a period of transition between the current carbon economy and the proposed hydrogen economy.
    a. Suggest a reason why nuclear fission does not appear on the flowchart for the carbon economy or on the flowchart for the hydrogen economy.
    b. Explain the role that nuclear fission could play during a period of transition between these two economies.